Studies on stand dynamic growth model for larch in Jilin in China

WENG Guo-qing [1], CHEN Xue-feng [2]
[1] Academy of Forestry Inventory & Planning, State Forestry Administration, Beijing 100714, P. R. China
[2] Department of Forest Resource Management, State Forestry Administration, Beijing 100714, P. R. China

Abstract: The stand growth and yield dynamic models for Larch in Jilin Province were developed based on the forest growth theories with the forest continuous inventory data. The results indicated that the developed models had high precision, and they could be used for the updating data of inventory of planning and designing and optimal decision of forest management.
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Introduction

Forest growth and yield models have been studied widely and intensively. For example, basal area models were developed for slash pine plantations by Pienaar *et al.* (1981), and for loblolly pine plantations by Sulliyan *et al.* (1972) and Burkhart *et al.* (1984), the survivor tree models were constructed for loblolly pine by Lemin *et al.* (1983), for radiata pine by Pienaar *et al.* (1973), for slash pine by Bailey *et al.* (1985), and both basal area and survivor tree stem models for loblolly pine were developed by Cao *et al.* (1982)

In China, however, the research on growth models of forest has been limited due to the fact that data sets used in analysis were from temporary plots and that there was no enough permanent plot data,. With the development of continuous forest inventory (CFI), tens of thousands of permanent plots have been measured and re-measured, which provides very high quality information on many factors. These valuable data of the plots warrant further development and application forest growth and yield models. The objective of this paper is to use CFI data for developing dynamic growth and yield models for larch in Jilin Province in China. The most recent inventory in Jilin indicated that larch comprises a high proportion of the forests.

Data collection

The data used in this study came from the re-measurements of Larch plantations in the CFI in 1984 and 1989 in eastern Jilin. Plot is 0.06 hm^2 in size. The diameter at breath height (DBH) of every tree in the plot and all stand factors are measured except the dominant height. For this research, only plots on which the trees had been measured on both occasions, the basal area was more than 65% of the whole stand and the crown closure was above 0.5, were used. The number of available plots was 112, and 82 of them were used for setting up the models and 30 for testing the models.

Development and selection of models

Mathematical expressions for static growth and yield models are as follows:

For a particular site quality: $Y=f(S, A)$

For variable site quality: $Y=f(S, A, SQ)$

where S is stand density; A is stand age; SQ is site quality; and Y is stand factors.

The feature of this kind of models is that the predictors are independent of the stand state at the beginning of the prediction.

Dynamic models are those whose predictors relate to the state of the stand at the beginning of the prediction. They can be expressed as:

For a particular site quality: $Y_2=f(S, A_1, A_2, y_1)$

For variable site quality: $Y_2=f(S, A_1, A_2, SQ, y_1)$

where Y_2 is prediction of the stand factors at A_2 of stand age; Y_1 is measurement of the stand factors at A_1 of stand age, and $A_2 \geqslant A_1$. It is obvious that Y_2 should be equal to Y_1 when A_2 equals A_1.

After some experimentation with the following models (equations 1 to 3), we found that these models were not very suitable for larch. Thus some more flexible models were needed.

$$\ln(Y_2)=\frac{A_1}{A_2}\times\ln(Y_1)+a\times\left(1-\frac{A_1}{A_2}\right)+b\times\left(1-\frac{A_1}{A_2}\right)\times SI \tag{1}$$

where a, b are parameters.

$$Y_2=Y_1\times\left(\frac{A_2}{A_1}\right)^{a1}\times e^{((a_2+a_3\times SI)\times(A_2-A_1))} \tag{2}$$

Biography: WENG Guo-qing (1963-), male, professor in Academy of Forestry Inventory & Planning, State Forestry Administration, Beijing, P. R. China. Email: wengyunfeng@sina.com
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$$\ln(Y_2) = a_0 + a_1 \times SI - \frac{A_l}{A_2} \times (a_2 + a_3 \times SI + \ln(Y_l)) \tag{3}$$

where a_0, a_1, a_2, and a_3 are parameters.

Researches by Pienaar *et al.* (1973), Weng (1989), and Li (1990) indicated that the parameter *k* could be described as a function of stand density and parameter *a* could be described as a function of site quality in Richards equation:

$$Y = a \times \left(1 - e^{(-K \times A)}\right)^c \tag{4}$$

where K and c are parameters.

That is, equation (4) could be described as:

$$Y = f(SQ) \times \left(1 - e^{(-f(S) \times A)}\right)^c \tag{5}$$

It can be assumed that the growth of stand factors is $\triangle Y$ when the length of the growth period is $\triangle A$. If $\triangle A$ is small enough, then

$$\Delta Y = f(SQ) \times \left(1 - e^{(-f(S) \times \Delta A)}\right)^c \tag{6}$$

Equation (6) is a function of growth. But it is a monotonic function, thus it is not reasonable theoretically. Especially it may produce large errors for fast growing species. Therefore some modification is needed for equation (6). For even-aged mono-species stands, stand growth depends on not only the length of period, but also stand age. Thus the term exp(d*A_1) is used as a modification factor. Equation (7) can then be obtained:

$$\Delta Y = f(SQ) \times \left(1 - e^{(-f(S) \times \Delta A)}\right)^c \times e^{(d \times A_l)} \tag{7}$$

where *d* is parameter.

Because $\triangle Y = Y_2 - Y_1$ and $\triangle A = A_2 - A_1$, they can be substituted into equation (7), and the final dynamic growth model is:

$$Y_2 = Y_l + f(SQ) \times \left(1 - e^{(-f(S) \times (A_2 - A_l))}\right)^c \times e^{(d \times A_l)} \tag{8}$$

Equation (8) is not a monotonic function and has only one maximum value. The beginning age of growth period at the maximum point is as follows:

$$A_l = A_2 + \frac{\ln\left[\dfrac{(d - c \times e^{(-f(S))})}{d}\right]}{f(S)} \tag{9}$$

Estimation of parameters and test and use of the models

Estimation of model parameters

Evaluation of site quality

Although dominant height was not measured, a site class table can be constructed to evaluate site quality with average stand height. The average stand height is defined as average height of all trees on the plot. To integrate site quality into the models, the average stand height at base age was used as an index of site quality. This index is different from site index, which is referred as site class index. The equation of site class index is:

$$SCI = \left[\frac{(1 - e^{(-.02035 \times A_0)})}{(1 - e^{(-.02035 \times A)})}\right]^{1.1278} \times H \tag{10}$$

where *SCI* is site class index; A_0 is base age (30 years); *A* is stand age; *H* is average stand height.

Determinations of the site quality function and stand density function

For simplicity, the site quality function is defined as:

$$f(SQ) = a' \times SI^{\,b} \tag{11}$$

and the stand density function is described as

$$f(S) = k' \times Y_1 \quad \text{or} \quad f(S) = k' \times \log(Y_1) \tag{12}$$

where a', b and k' are parameters.

Results

Equation (8) can be solved by least square. Then the optimal parameters are estimated with Maquardt logarithm using the least square parameter estimates. The goodness of fit criteria is residual sums of square and the coefficient of determination.

The results indicate that equation (8) is much better than equations (1), (2), (3), and (6). The parameters and the goodness of fit criteria are list in Table 1.

Table 1. Parameters and Goodness of Fit of Models

Stand Factors	Density Function	Parameters					Goodness of fit	
		a'	b	k	c	d	SSR*	R^{2**}
Volume	k'* Y_1	1.8485	0.6734	0.6911	1.8475	0.0088	4780.7	0.9725
Mean Diameter	k'* Y_1	1.7435	0.1157	0.06859	-0.6656	-0.03297	27.3	0.9851
Basal Area	k'* Y_1	1.6681	0.321	0.053	0.4103	-0.01285	153.9	0.9702
Number of Stems	k'*ln(Y_1)	12.26	0.3139	0.00505	2.0566	0.00975	27307	0.9994

Test of Models

Precision indexes

The relative difference between the prediction value and the actual value of stand factors (*RE* or *RD*), relative difference percent (*RDP*) and its absolute (|*RDP*|), standard deviation (*SdRDP*) and standard error (*SdeRDP*) are used as precision indexes. The formulae are:

$$RE = \frac{\left(\sum_{i}^{n} Y_2' - \sum_{i}^{n} Y_2\right)}{\sum_{i}^{n} Y_2'} \times 100 \quad (13)$$

$$RDP = \frac{\sum_{i}^{n} \frac{(Y_2'-Y_2)}{Y_2'}}{n} \times 100 \quad (14)$$

$$|RDP| = \frac{\sum_{i}^{n} \frac{|(Y_2'-Y_2)|}{Y_2'}}{n} \times 100 \quad (15)$$

The relative difference (*RE*) between the predicted mean and the actual mean of stand factors indicates the precision of the predictor of totals. Percent of relative difference indicates the average relative difference between the predictor and real value for a single stand. Moreover, it reflects the difference between the actual value and prediction of the total. Thus the *RE* should be used as a precision index of model fit when the model will be used for macro decision-making (Forest planning). The absolute value of relative difference percent reflects the average difference of actual value and prediction for one stand in the total, so the *RDP* should be used as the precision index when the model will be used for micro decision-making (For example, forest management).

Testing results with the dependent data set

The results of testing models with the dependent data set are listed in Table 2. Table 2 shows that the estimates of total means of all stand factors have high precision (error less than 1%). By comparison, the estimates for single stand have lower precision. For example, when the total volume is estimated, its precision is about 99.85% (100–0.1516). But when one stand volume is estimated, its precision is about 87.9% (100–12.0875).

Table 2.Testing results with dependent data set

Stand factors	*RE*	*RDP*	*IRDP I*	*SdRDP*	*SdeRDP*
Number of stems	0.8142	0.8205	0.8207	0.0333	0.0972
Mean diameter	0.1367	0.1776	4.583	0.0932	0.696
Basal area	0.0880	0.6314	13.89	0.1865	2.7886
Volume	0.1516	2.8266	12.0875	0.1534	1.9806

Testing results with the independent data set

The results of testing models with independent data set are listed in Table 3.

Table 3. Testing results with independent data set

Stand factors	*RE*	*RDP*	*IRDPI*	*SdRDP*	*SDeRDP*
Number of stem	-0.6587	-0.6973	0.7007	0.0702	0.1515
Mean diameter	-0.5043	-1.0764	5.1633	0.2206	1.3558
Basal area	-1.312	-2.7789	9.597	0.283	2.4386
Volume	-4.514	-3.6682	11.045	0.3014	2.9329

Table 3 shows that the models have a little lower precision when they are used for an independent data set, but the precision are still high. Their *RES* are less than 5%, and I*RDP*I are not significantly different from that of the dependent data set.

Coordinating the relationship among the number of stems, mean diameter and basal area

The relationship among the number of stems, diameter and basal area is known as following:

$$\text{Basal Area} = \frac{3.1416}{4} \times \text{ number of stem} \times (\text{Mean diameter})^2 \quad (16)$$

It is obvious that equation (16) does not exist when the basal area, number of stems, and mean diameter are separately calculated with models. The precision of the basal area calculated by the two methods are given in Table 4. It suggests that the basal area can be calculated by either of the methods.

Table 4. Precision comparison of basal area

Type of data set	Estimation method of basal area	*RE*	*RDP*	I*RDP*I	*SdRDP*	*SdeRDP*
Independent	Method A	-1.3124	-2.7789	9.5970	0.2830	2.4386
	Method B	2.9514	-1.1380	11.7335	0.3390	3.1484
Dependent	Method A	-0.08796	-0.6314	13.8900	0.1865	2.7886
	Method B	-.5107	-2.6603	10.8900	0.1428	1.7177

Note: Method A: Calculated with mean diameter and number of stems; Method B: Calculated with model directly.

Use of models

The test results indicate that the dynamic stand model has high precision and can be used for predicting total or single stand growth. Since the length of the growth period is 3 years in the original data, it has the most precise predictors when $A2=A1+3$ in practice.

The state and the dynamic changes in the period of prediction of specific stand are taken into account in dynamic stand growth models. Since highly accurate predictors can be obtained with the models, the models can be used for stand management strategies.

The model can be used for forest resource file management. Their highly precise predictors can be used for updating the data of the compartment in resource file management.

Dynamic stand models can be used for predicting the stand diameter distribution and timber ratio. Substituting the prediction of the models for the parameter prediction models or parameter recovery models to calculate the parameters of stand diameter distribution and estimate the number of stems for every diameter class further. The timber ratio can then be estimated with the assortment model.

Conclusion

The dynamic stand models for larch plantations were established with continuous forest inventory data. The results of tests indicated that the models had high precision. They also showed that the continuous forest inventory data can be used not only for macroscopic decision-making, but also for stand management strategies.

The stand site quality had to be evaluated with average stand height because of the absence of dominant height data. But the results of testing the models show that site class index can evaluate site quality. However, even better results can be expected with suitable site index tables.

Accurate predictions for specific stands produced with the models can be used for stand management strategies and forest resource management, especially for renewing compartment data in forest resource files.

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